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Journal of Horticultural Research 2019, vol. 27(1): 31-36
DOI: 10.2478/johr-2019-0004

HYDROPONIC pH MODIFIERS AFFECT PLANT GROWTH AND NUTRIENT CONTENT IN LEAFY GREENS

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Received: April 2019; Accepted: June 2019

ABSTRACT

Use of hydroponics is increasing because of its ability to be used for year round vegetable production using an environmentally sustainable system. Management of solution pH is an important challenge in hydroponics systems. Our objective was to quantify the effects of various pH modifiers on growth and nutrient uptake of leafy greens and stability of nutrient solution's pH. Lettuce, basil, and Swiss chard were transplanted into an Ebb and flow system, and nutrient solution pH was maintained using three different pH modifiers (pH Down, lime juice, or vinegar). The nutrient solution's pH was maintained between 5.5 and 6.5. pH Down resulted in the most stable solution pH and required the least amount of product used when compared to lime juice and vinegar. The cost of using phosphoric acid or lime juice was greater than that of using vinegar. Vinegar reduced the yield of all crops in comparison to pH Down. When compared to pH Down, lime juice reduced the yield of basil and Swiss chard but not that of lettuce. Therefore, growers can use lime juice as an alternative to pH Down in lettuce production but not for basil and Swiss chard, while vinegar would not be recommended for any of the crops studied.

Keywords: soilless culture, nutrients, lettuce, basil, Swiss chard, chlorophyll meter

INTRODUCTION

By 2050, the human population is expected to reach 8.9 billion (USAID 2004), and a major challenge for the increased population will be maintaining the supply of fresh produce to ensure nutrient-rich diets. Hydroponic or soilless production could be an important solution to this problem because of its higher yields and more nutritious food when compared to soil production (Skagg 1996). Hydroponics can be defined as a technique of growing non-aquatic plants without soil in a nutrient solution with or without soilless substrate (Arancon et al. 2015). Maintaining an adequate nutrient solution and pH level are often cited as major obstacles to hydroponic production (Steiner 1961). Frick and Mitchell (1993) indicated that pH of a hydroponic nutrient solution fluctuates because of the unbalanced anion and cation exchange reaction with roots and there is no buffering capacity in hydroponics as in soil.

Plant essential nutrient availability varies with pH. According to Resh (2004), slightly acidic pH is optimum for hydroponic production because iron (Fe), manganese (Mn), calcium (Ca), and magnesium (Mg) may form precipitates and become unavailable at pH above 7. Islam et al. (1980) reported that at higher pH, the amount of Fe, Mn, Mg, potassium (K), and Ca increased in the plants, but these elements were not translocated to the shoot but instead remained stored in the roots. Bugbee (2003) also reported that availability of K and phosphorus (P) is slightly reduced in a nutrient solution with high pH. Dyśko et al. (2008) also reported that the increase in nutrient solution's pH led to the decrease in available P for hydroponic production of tomato (*Solanum lycopersicum* L.). Chen et al. (2016) also reported a difference in nutrient uptake of lettuce

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with solution pH when using wood vinegar. Hochmuth (2001) recommended a nutrient solution's pH of 5.5–6.5 for greenhouse hydroponic production, whereas Resh (2004) recommended a pH of 5.8–6.4. Ahn and Ikeda (2004) also reported a pH of 5–7 as optimum for hydroponic cultivation of Chinese chive (*Allium tuberosum* Rottler ex Spreng.). Whipker et al. (1996) various studies examining optimum pH for hydroponic lettuce (*Lactuca sativa* L.) production reported a decrease in leaf area, shoot dry weight, leaf length and width, and stomatal conductance because of the exposure to a suboptimal solution pH.

There are various chemicals that can be used to lower the pH of a nutrient solution in hydroponics. Burleigh et al. (2008) recommended the use of citric acid (lime juice), acetic acid (vinegar), nitric acid, phosphoric acid, and sulfuric acid for lowering pH of the water used for plant cultivation. Chen et al. (2016) also reported that pyroligneous acid (wood vinegar) can be used for hydroponic cultivation of lettuce at a rate of 0.25 $ml \cdot dm^{-3}$ while evaluating different strengths of wood vinegar as a pH buffer. Frick and Mitchell (1993) compared the use of 2-(N-morpholino)ethanesulfonic acid (MES) buffer and Amberlite DP-1 (cation-exchange resin beads, 16–50 wet mesh, 8.1 $mEq \cdot g^{-1}$) for stabilizing the pH of nutrient solution for the production of mustard (*Brassica juncea* L.). The concentration of chemicals used for pH stabilization can also affect plant growth. Stahl et al. (1999) used different concentrations of MES for hydroponic culture and concluded that plant growth was affected with increasing concentrations. Stabilizing the pH of a nutrient solution is necessary for optimum crop productivity in hydroponics (Frick & Mitchell 1993). Identifying a more economical and readily available product for reducing the pH of the solution without reducing the crop yield would be beneficial to growers (Kirimura & Inden 2005). Therefore, the objective of this study was to evaluate the use of lime juice, vinegar, and a commercial pH buffer (pH Down) as pH modifiers in hydroponics and their effect on plant growth, chlorophyll content, and nutrient uptake of leafy greens.

MATERIALS AND METHODS

Plant material and growth conditions

The research was conducted at the Department of Horticulture and Landscape Architecture Research Greenhouses in Stillwater, OK, under natural photoperiods. Temperature was set at 21 °C/18 °C day/night with a photosynthetic photon flux density (PPFD) range of 600–1,200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at 1,200 HR. Seeds of red lettuce 'Oscarde', basil (*Ocimum basilicum* L. 'Citrus') and Swiss chard (*Beta vulgaris* L. 'Magenta Sunset'), were obtained from Johnny's Selected Seeds (Winslow, ME). Seeds were sown in 1.5 cm^3 rockwool starter cubes (Gordan, Milton, ON) on 2 February 2017. A styrofoam sheet was used to support the plants, and 5 cm diameter slots were drilled into the sheet with a spacing of 28 cm × 28 cm. Upon obtaining two true leaves (March 6, 2017), plants were transplanted into 5-cm net pots on Ebb and flow tables (Gro Master, Maple Park (Virgil), IL). Plants were randomly assigned to 1 of 30 net pots on each of 3 tables resulting in 10 replicates of each crop species per table. Each table was randomly assigned one of the three pH modifier treatments: white vinegar (5% acidity; Wal-Mart Stores Inc., Bentonville, AR), lime juice (1.06 $g \cdot oz^{-1}$ citric acid; Dr. Pepper Snapple Group, Plano, TX), and pH Down (General Hydroponics, Santa Rosa, CA). The lime juice was diluted to reach a pH of 2.5 similar to the other two products. The plants were harvested 30 days after transplanting. The entire experiment was repeated three times with planting also occurring on 20 March and 25 April 2017 and transplanting occurring on 25 April and 3 June 2017 for the second and third runs, respectively.

Fertilizers and EC

The nutrient solution was designed using a commercially available soluble fertilizer (Peters 5-5.2-21.6, J.R. Peters Allentown, PA), calcium nitrate (American Plant Products), and local tap water (EC = 0.5 $mS \cdot cm^{-2}$, pH = 7.8). Initial solutions were produced using manufacturer recommendations of 147.41 $g \cdot dm^{-3}$ of Peters and 97.52 $g \cdot dm^{-3}$ of calcium nitrate. The hydroponics system had a 141.4 dm^3 of tank capacity and was circulated using a 189 $dm^3 \cdot min.^{-1}$ pump (Wayne, Harrison, OH).

The EC and pH of the solution were measured every other day using a pH/EC meter (Hanna Instruments, Woonsocket, RI). The EC of the nutrient solution was checked every other day to maintain the EC at 1.5–2.5 $ds \cdot m^{-1}$ and the pH at 5.5–6.5 by adding fertilizer and pH solution.

Data Collection

At the end of the study, data were collected on fresh shoot weight and dried shoot and root weight (plants cut at substrate level and dried for 2 days at 56.6 °C). Three leaves (top, middle, and bottom) from each plant were scanned using a SPAD-502 chlorophyll meter (SPAD-502, Konica Minolta, Japan) at the time of harvest. Dried shoot samples were analyzed for nitrogen content by the Soil, Water and Forage Analytical Laboratory (SWFAL) at Oklahoma State University, using a LECO TruSpec Carbon and Nitrogen Analyzer (LECO Corporation, St. Joseph, MI).

Statistics

The experimental design was a split-plot design with 3 replications of 10 individual replicates per species per run; Factors were pH-lowering products (three levels) and species (three levels). Data were subjected to an analysis of variance (ANOVA) using PROC MIXED with the LSMEANS statement and DIFF option within the SAS/STAT software, version 9.4 (SAS Institute, Cary, NC). Tests of significance are reported at the 0.05, 0.001, and 0.0001 levels. Treatment means were separated using Fisher's protected least significance difference (LSD) method. Statistical analyses were conducted for each crop separately.

RESULTS

Effect of different pH products on nutrient solution's pH

Nutrient solution's pH increased on a near-liner trend for all three modifiers; however, pH Down appeared to plateau around a pH of 6.7 starting around 25 days (Fig. 1). The pH was in the required range (5.5–6.5) throughout the growth cycle for treatments using phosphoric acid, whereas for treatments using lime juice and vinegar, the pH reached 7.5 at harvest (Fig. 1). Across the three experimental runs, the total amount of lime, vinegar, and pH Down used per run was 6,000 ml; 8,000 ml; and 600 ml, respectively.

Effect of different pH products on growth and chlorophyll content of lettuce, basil, and Swiss chard

The fresh weight and dry shoot weight of lettuce were significantly lower with vinegar than with the other treatments, while there was no significant difference between lime juice and phosphoric acid (Table 1). There was no significant difference in dry weight of lettuce roots among the treatment groups. The SPAD values were lowest for lime juice, and there was no significant difference between vinegar and phosphoric acid (Table 1).

The fresh and dry shoot weight of basil was significantly greater for phosphoric acid than other pH modifier treatments. The dry root weight of basil was significantly lower for vinegar than other treatments, whereas no significant difference was observed between lime juice and phosphoric acid. The SPAD values were significantly greater for phosphoric acid than for lime juice or vinegar (Table 2).

The fresh and dry shoot weight of Swiss chard was greatest for plants grown with phosphoric acid (Table 3). The dry weight of Swiss chard roots was lowest using vinegar, whereas no significant difference was observed between among lime juice and phosphoric acid. No significant difference was observed for SPAD values among all three treatments of Swiss chard (Table 3).

Effect of different pH products on nutrient content of lettuce, basil, and Swiss chard

Nitrogen (N) and K contents for lettuce and basil were significantly lower for the lime and vinegar treatments when compared to the phosphoric acid treatment (Table 4). This corresponded to lower SPAD values in both lime- and vinegar-treated nutrient solution when compared to that treated with phosphoric acid. There was no significant difference in the P content among the different treatments for either lettuce or basil; also, there was no significant difference in N or K content among treatments for Swiss chard (Table 4). Plant micronutrient content was not affected by pH buffer treatment (data not presented).

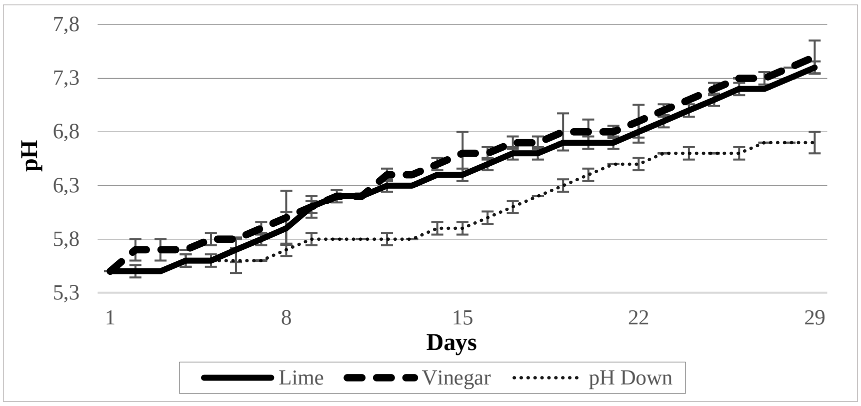

Fig. 1. Nutrient solution's pH before adjustment during the production of lettuce 'Oscarde', basil 'Citrus', and Swiss chard 'Magenta Sunset'

Table 1. Effects of different pH modifiers on 'Oscarde' lettuce growth and chlorophyll content after 30 days in Ebb and flow system (n = 30)

Treatment	Shoot FW (g)***z	Shoot DW (g)**	Root DW (g)NS	SPAD*
pH Down	235.9 ay	7.7 a	0.7 a	22.2 a
Lime juice	210.8 a	7.8 a	0.8 a	20.5 b
Vinegar	116.7 b	5.7 b	0.7 a	22.6 a

z indicates significant at or non-significant (NS) at *$p \leq 0.05$, **$p \leq 0.001$, or ***$p \leq 0.0001$
y LS means within a column followed by same lowercase letter are not significantly different by pairwise comparison in mixed model ($p \leq 0.05$)

Table 2. Effects of different pH modifiers on 'Citrus' basil growth and chlorophyll content after 30 days in Ebb and flow system (n = 30)

Treatment	Shoot FW (g)***z	Shoot DW (g)***	Root DW (g)*	SPAD*
pH Down	293.0 ay	24.6 a	4.2 a	26.0 a
Lime juice	213.6 b	19.1 b	4.3 a	24.5 b
Vinegar	151.8 c	13.4 c	3.3 b	23.6 b

Note: see Table 1

Table 3. Effects of different pH modifiers on 'Magenta Sunset' Swiss chard growth and chlorophyll content after 30 days in Ebb and flow system (n = 30)

Treatment	Shoot FW (g)**z	Shoot DW (g)**	Root DW (g)*	SPADNS
pH Down	187.7 ay	10.9 a	1.4 a	42.6 a
Lime juice	118.8 b	7.6 b	1.0 a	42.1 a
Vinegar	50.1 c	4.3 c	0.3 b	42.0 a

Note: see Table 1

Table 4. Effects of different pH modifiers on macronutrients element of lettuce 'Oscarde', basil 'Citrus', and Swiss chard 'Magenta Sunset' (n = 3)

Treatment	Nitrogen (%)			Phosphorus (%)			Potassium (%)		
	lettuce**z	basil**	Swiss chardNS	lettuceNS	basilNS	Swiss chardNS	lettuce*	basil*	Swiss chardNS
pH Down	4.8 ay	5.2 a	4.3 a	0.7 a	1.3 a	0.4 a	6.2 a	0.8 a	2.1 a
Lime juice	4.4 b	4.2 b	4.5 a	0.7 a	1.3 a	0.4 a	6.0 b	0.6 b	2.2 a
Vinegar	4.8 a	4.2 a	4.1 a	0.7 a	1.3 a	0.5 a	6.1 b	0.7 b	2.1 a

Note: see Table 1

DISCUSSION

The authors hypothesize that the initial delay in pH increase may be because the nutrient uptake was less during the first week because of the small size of the plant as well as a smaller leaf surface area for transpiration of water. During the second week, as the plants grew, more nutrients and water were taken up. This may have led to an uneven uptake of anions and cations, which is one of the causes of pH change in a nutrient solution (Frick & Mitchell 1993). Chen et al. (2016) also reported that pH was more stable during the first week of the growth cycle but increased thereafter. In contrast to the results of the present study, Lee and Lee (2006) reported that because of balanced nutrient uptake during the growth cycle, the nutrient solution pH remained stable during hydroponic production of leafy greens. Because our water pH is alkaline (pH 7.8), adding water to replenish levels in the tank increased the pH. According to Sinclair and Eny (1946), juices such as lemon juice consisting of citric acid can also be used as an organic buffer to resist changes in the pH when hydrogen or hydroxyl ions are added. In this study, citric acid alone was only effective for a day then the pH increased steadily, whereas with pH Down, which also contains citric acid, ammonium dihydrogenorthophosphate, and phosphoric acid, the pH level did not fluctuate as rapidly and stabilized at the end.

The color of leafy green vegetables is an important attribute affecting consumer preference (Ali et al. 2009). Chlorophyll meters can be used to estimate the greenness of leafy green vegetables as Colonna et al. (2016) used a SPAD meter to estimate nitrogen (N) content of leaves as a nondestructive method. Singh et al. (2019) reported that SPAD values ranged from 17 to 28 for different cultivars of lettuce, which corresponded with our values, but found 'Oscarde' to have a greater SPAD value. The lower SPAD values for basil treated with lime juice and vinegar corresponded to visual observations of chlorosis and lower tissue N content. Chen et al. (2016) found that use of wood vinegar at high concentrations (1 $ml \cdot dm^{-3}$) in hydroponic lettuce production may lead to decreased nitrate-N uptake, photosynthesis rate, and chlorophyll content. In contrast, the lower SPAD values for lettuce plants treated with lemon juice did not show evidence of chlorosis, which may be the result of using a red leafed cultivar.

Generally, inorganic acids such as nitric acid, sulfuric acid, and phosphoric acid are used for reducing and stabilizing the nutrient solution's pH in hydroponic production. This may also affect the nutrient composition of the solution as nitric acid may contribute to the nitrate form of N and sulfuric acid may contribute to sulfate ions and it would be hard for a normal grower to calculate the amount of nutrients added every time the pH buffer is added (Chen et al. 2016). Lei et al. (2004) reported hydroponic vegetables to be higher in nitrate concentration as compared to soil grown vegetables, which is harmful for human consumption. Greater leaf nitrogen and potassium values were observed for 'Oscarde' and 'Citrus', which is not unexpected for pH Down containing additional ammonium and phosphates. The additional nitrogen was unexpected for vinegar, which is derived from ethanol to produce acetic acid. Kirimura and Inden (2005) reported that using safe, natural, and less-expensive acidic material is more beneficial for hydroponic production as compared to inorganic acids. This contradicts what we found, as vinegar and lime juice reduced the plant growth for 'Citrus' and 'Magenta Sunset' and reduced the plant quality in 'Oscarde' compared to pH Down. The effect of lime juice and vinegar on basil and Swiss chard may be due to the use of too high of concentrations to maintain a desirable pH level.

CONCLUSION

From the results of the present experiment, lime juice or pH Down can be used as a pH modifier for hydroponic production of 'Oscarde' as chlorosis is not prominent in red cultivars. For hydroponic production of basil, only pH Down should be used, because the use of lime juice and vinegar leads to lower SPAD values (chlorosis), less N uptake, and reduced growth. For Swiss chard, pH Down would be recommended for greater growth. For all three species, pH Down had lower production costs of $2.60 compared to $8 and $26.40 for vinegar and lime juice, respectively, and had a greater affect at maintaining the pH.

Future research should investigate the use of different organic acids, concentrations, combination with other buffering compound, or different cultivars of basil, Swiss chard, and lettuce.

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